having two distinct foci separated by about half an inch, and, if bright enough, can be distinguished from ordinary stars merely by the aspect of the image. The visibility of planetary details differing greatly in color from the general surface tint, would doubtless be much affected by the same peculiarity of large telescopes. Thus, a fine blue line on the surface of *Jupiter* would be spread out into a diffuse band of considerable width at the visual focus, and, if faint, would certainly escape detection. Such differences of focus have been noticed in making drawings of *Mars* during the opposition of 1890. This is a subject of importance, and one which has as yet received little attention.

ARE THE PLANETS HABITABLE?

A Lecture delivered before the Catholic University of America, by Rev. George M. Searle.

Having completed our survey of the planetary system in which we live, a question naturally occurs to us, which has occurred to every inquiring mind since the real dimensions of the orbs belonging to it were known. To the great majority of mankind it is, and is rightly, a question of greater interest than any one with which mathematics or physics has to deal; of greater interest, since life is a much higher and nobler thing than machinery, and the spiritual far above the material. This question is, "Are these planets which, like our earth, move in their appointed paths around the sun, and on which there is certainly ample room for a population far greater than what our globe could support, actually inhabited by beings in any way like ourselves?"

Almost every astronomer has probably been asked what his views are on this question, and whether his science has anything to tell us about it. At each successive increase in the size of telescopes, men vaguely hope that with the new optical power it may be possible to discover some signs of sentient, and perhaps even of intelligent, life in the celestial worlds. "How much does this telescope *magnify?*" is always the interesting question to the popular mind. The professional astronomer perhaps is not looking so much for that. He wants to get more light; to see and to delineate faint nebulæ, to follow a comet as far as he can into the darkness of space, in order

to determine its orbit as well as possible; but the world in general has comparatively little sympathy with him in this. The discovery of one intelligent being outside this planet of ours would be more interesting to most men here than all the comets which ever have been, or ever will be seen.

Is it then possible that the power of telescopes will at any time be so increased that any discovery of this kind can be made? That is what people would like to know. Let us answer this question in the first place.

The moon is our nearest neighbor. If we can magnify enough to see an object the size of a man on any of the planetary orbs, we must first be able to see such an object on the moon. Is it possible to obtain a magnifying power sufficient for this?

It is possible, we answer, to have such a magnifying power; but the difficulty is to avail ourselves of such a power when we have got it. The great and turbulent sea of atmosphere which lies above us, is a seemingly insuperable difficulty. To some extent, of course, we can get free from this by placing our telescope on some high mountain; but there is no mountain high enough to place us altogether out of the atmosphere, and if there were one, we could not live or carry a telescope there. At the highest point at which observations would be possible, which probably would be a good deal below the summit of the Himalayas, enough air still would remain above us to prevent our using a power high enough to discern men like ourselves on the face of our satellite. The tremulousness and waviness produced in the telescopic image by the air, which is, of course, increased the more we magnify, would hopelessly obscure outlines so delicate as those here concerned, and make of such small points a simply invisible blur.

Even for the moon, then, the direct discovery of animal life by increased optical power, would seem to be a dream which will never be realized. The difficulty, of course, is immensely increased for any other celestial object. No other planet comes nearer to us than about one hundred times the moon's distance; and, moreover, in examining them, we should have to contend with the confusion of outlines coming from their atmospheres as well as from our own.

We may then as well give up hope of trying to answer the question, "Are the planets inhabited?" as one which never will be solved for us in this world by any natural means; and fall back on another, on which science, certainly, can give us some light, namely: "Are they *habitable;* are the physical conditions such in them, so far as

we can ascertain, that the life of man or of any highly organized animal, could there subsist?"

Now, I say the "planets"; for it seems to me that we may as well put the great central body of our system, the sun itself, out of the question. From what has been said regarding it in previous lectures, I think it is pretty clear that the surface at least of this enormous globe is in such a state as to make it absolutely impossible for us to conceive of any organized life existing there. It is true that we do not know exactly how much complexity of structure is required in matter as a basis of life; but we can hardly consider life in the proper sense as belonging to a chemical molecule, and everything would indicate that on the surface of the sun matter is reduced to its simply chemical or molecular state. Any structures or organisms which we call alive, would instantly be destroyed in that intense flame; even inanimate shapes, like those of crystals, would not survive its action for a moment.

But may there not be a cooler region below the sun's surface, protected in some way from the intense heat of the exterior? Such a theory was entertained in the last century and even in this; but it is pretty safe to say that no one now would hold it. That it should have held its ground so long is due perhaps in great measure to the authority of Sir WM. HERSCHEL. I do not think it was ever satisfactorily explained just how the interior was protected from the immense radiation of its envelope; certainly, it is hard for us to see nowadays, knowing as we do the radiating power of the surface (10,000 horse-power per square foot, you remember, we found it to be) how such a blaze as this could even be supposed to be cut off from any point within. To suggest a cool place in the interior of the sun is much as if one should advise a person suffering from the heat of a furnace to wrap himself up well, and take a seat inside. Moreover, we know from spectroscopic indications now, particularly from those of oxygen in the sun, that the further in we go, the hotter it gets; and this also would follow from the only theory which can reasonably account for the formation of the sun, and the maintenance of its heat—that of HELMHOLTZ, previously mentioned.

We may pretty certainly say, then, that in any common-sense way of using the word, the sun is not habitable. Absolutely speaking, of course, all space is habitable; there is no conclusive reason why an organized being should require nutriment or air, and hence an animal might be conceived as being launched into space as a planet on his own account. But what we mean by a place being habitable is, that

it should furnish the requisites and conveniences belonging to a life similar in its principal features to that with which we are acquainted. It is not a thing which can be strictly defined; nevertheless, we know well enough for practical purposes, what we are talking about; and we know that such a place as this empty space is not "habitable."

From the consideration of the sun we will pass to that of the next most conspicuous object to us in the planetary system; that is to say, the moon. I have already expressed in a previous lecture the views generally entertained by astronomers about the moon. It is pretty certain that the side of it which we see offers nothing in the way of a convenience of life except mere standing-room. There is hardly a doubt that its surface consists simply of bare rock, unvaried by water, soil, or any kind of vegetation; that if there be any atmosphere upon it, it is so excessively rarefied as to be, for purposes of life, practically equivalent to none.

As to the other side, of course, we can say nothing positively. It may perhaps in some way be different from this. But taking the ordinary and (to say the least) very probable view as to the method of formation of the planetary masses, by cooling from a liquid condition, it is hard to see how there could possibly be any considerable difference of shape or of density between the half of the lunar sphere which is turned towards us, and that which is turned away. And unless there be such a difference, the other side must be as destitute of atmosphere as this; and if of atmosphere, of water as well; for the water or other fluid, if existing in any quantity, would form an atmosphere, if none previously existed.

The moon then hardly seems to present the condition required for what we should call a habitable planet; though it fails in a very different way from the sun. The moon is dead; the sun is too much alive. The moon may have been habitable and inhabited once; the sun may be in the future.

So far, our survey has not been very encouraging. But we have not yet considered the planets properly so-called.

In considering them from this point of view, let us proceed in the contrary order to that which we followed in describing them in detail. Let us start at the outer limit, with the great twin planets, as we may call them, on account of their great similarity, widely separated in space as they are, namely *Uranus* and *Neptune*.

These would perhaps generally be imagined as very cheerless habitations for intelligent beings, on account of their distance from the sun, and the comparatively small amount of light and heat which

that great central fire sends to them, if that which the earth receives be taken as the standard. Particularly would this impress us in the case of *Neptune*. Its distance from the sun is about thirty times ours, and, according to the oft-repeated law of the inverse squares of the distances, the light and heat which it gets from the sun is only one nine-hundredth part of that which we receive. But let us not give up the matter as hopeless on this account. One nine-hundredth part of sunlight is not such a faint illumination after all. It is nearly 700 times the light of the full moon, and indeed equal to that given by a large electric arc-lamp at a distance of a few feet. There would be no difficulty about reading by means of it; it would be quite sufficient for all the ordinary practical purposes for which sunlight is used here. And then there is another consideration which is of very great weight.

It is this: You know that, as I have said, what astronomers increase the size of telescopes for is to gather more light, rather than to get greater magnifying power. A telescope of two inches diameter, or aperture, as it is technically called, will give four times as much light as one of only one inch; one of ten inches will give twenty-five times as much as the two-inch, or a hundred times as much as the one-inch. The great Lick telescope, of three feet aperture, makes a star look about thirteen hundred times as bright as a one-inch spy-glass, and enables us to see stars about twenty thousand times fainter than any which can be seen with the naked eye. And the same rule would hold for the eye itself. If we should increase the size of the pupil of the eye, we should see fainter objects than we do now; and we indeed actually do this when we go from bright light into a dark room. We can easily see how the pupil dilates to accommodate itself to reduced light, by simply examining another person's eye in these changed conditions, or our own before a looking-glass. The eye of a cat changes much more. If the retina of the cat's eye is as sensitive as our own, she must habitually see stars five or six times fainter than any which we can discern without a glass, and the heavens must present to her a magnificent appearance, if she cares to look at them. Probably she actually uses this increased light rather to discover mice than stars; but her astronomical opportunities are there all the same, though she may not avail herself of them.

It is true that this increased light is obtained in the eye at some sacrifice of definition, or sharpness of vision in detail; but still an inhabitant of *Neptune* might have a good deal larger pupil than ours in proportion to the size of his eye than ours. And then again, there

is no reason why the retina itself should not be made much more sensitive to light than ours; and here we have an increase which has no limit, so far as we can tell. It would be an injury to us to have our optic nerve more sensitive; the strong sunlight to which we are exposed would hurt us. But there is no reason why the Neptunians should not have what would be a benefit to them.

The whole question, then, of light in the solar system is one of little consequence; eyes could easily in any planet be such as to suit the exigencies of the case.

With regard to heat, the question is a little more difficult, but not very much. If we should assume that the 500 degrees Fahrenheit by which our temperature here is raised above that of space are simply due to our distance from the sun, and that *Neptune* could only have one nine-hundredth part of that, of course the temperature there would practically be that of space itself, or 460 below the Fahrenheit zero. But we know that in fact the genial warmth of the earth is in a great measure due to its atmospheric garment or blanket; and we cannot be at all sure that an atmosphere may not exist on *Neptune* which may make the absorption so much greater than the radiation that an equality between the two would not be reached before the planet had accumulated from its scanty solar supply enough to make its temperature equal to ours.

And, besides, there is no certainty that these great outer planets may not still retain a great deal of their own intrinsic heat; that they may yet be warm enough, even on the surface, to act as a source of heat to their inhabitants. Indeed, the danger here is rather that they are too hot than too cold. Yes, that is the trouble with all the great outer planets, with *Jupiter* and *Saturn*, as well as *Uranus* and *Neptune*, as we shall shortly see. As far as atmosphere is concerned, the spectroscope would indicate rather a dense one on both *Uranus* and *Neptune*, and of the same character on each. *Uranus* shows belts on its surface similar to those seen on *Jupiter*; but we cannot be sure that this indicates a similar constitution in the two planets. On the whole, we may say that there is quite what we may call a probability that *Uranus* and *Neptune* are in a habitable condition; the probability is, however, as we may say, rather negative than positive; we cannot give any certain reason why they should not be; but there are really no positive indications to show that they are fit to be the abode of life. The arguments against habitability become much stronger in the case of the two giants of the planetary system, *Saturn* and *Jupiter*, which come next in order

as we proceed toward the sun. The brilliancy of *Jupiter's* surface, and the rapidity of the changes which we see there, exceeding what the moderate light and heat which it receives from the sun would be likely to produce, seem to be quite strong arguments that it is still in a condition to emit light and heat to a considerable extent on its own account; and, indeed, that its temperature is still sufficient to keep it in a fluid state. If its surface be indeed in the condition of molten metal, it certainly becomes uninhabitable in the common-sense view of the subject; for in melted metal no organism composed of ordinary chemical elements could possibly subsist.

These arguments apply with somewhat diminished force to *Saturn.* Another, however, which may perhaps be derived from the lightness or small density of all the four great exterior planets of which we have been speaking, is strongest in the case of this one. This lightness may indicate that they have not yet shrunk to their proper dimensions; for it seems reasonable enough to suppose that the chemical constituents throughout the solar system are the same; that all the planets are chips out of the same block; and that when all reduced to the physical state of the earth they would have about the same density. But this does not seem to amount to much; for though it holds well enough in the cases of *Mars* and *Venus*, it notably fails in that of *Mercury*, if the determinations of the mass of that planet can be considered as trustworthy. The density of *Mercury* would appear, it will be remembered, to be twice that of the earth; which would prove most undoubtedly that it was made of decidedly heavier materials, unless we maintain that it is very much more solidified than the earth; which would seem to be improbable. When a planet has once become, like the earth, solid on the surface, no further perceptible shrinkage is possible except by a complete breaking up of the crust, which could hardly result except from a collision.

But to return to the great planets of which we have been speaking. I think few, if any, astronomers believe them to be habitable in their present condition; for, though the case is more doubtful for *Uranus* and *Neptune*, still they have, in their general features, so much resemblance to *Jupiter* and *Saturn*, that it is usually presumed that they are in the same state. But no one could pretend to be certain with regard to the matter.

Before we leave this portion of our system, however, we must not omit a part of it which is eminently worth considering with reference to the present question. I mean the numerous satellites, which are such a striking feature in it.

Let us consider specially those of *Jupiter*, about which we know the most. The four moons of *Jupiter* are all quite considerable bodies, ranging in size from that of our moon to that of the planet *Mars*. There is plenty of room on them for a very large population; the surface of the largest does not fall far short of that of the land part of our own globe. There is no reason why they should not be in the same general physical state as the earth is; we have already seen that, as far as light and heat are concerned, they may be considered as amply provided; perhaps, indeed, even better than we; for the great planet itself, round which they circulate, would probably serve as a much better luminary by night than our own moon, and may very probably contribute not a little to keeping them comfortably warm, if it is indeed still in a melted and glowing condition. We may well believe that it is indeed a second sun to them, and if the satellites of *Jupiter* keep, like our own moon, the same side always turned toward the primary planet, that favored side would enjoy a continual warmth, which might indeed be excessive.

Similar remarks may, of course, be made of all the other satellites which we find in this great region, revolving round *Saturn*, *Uranus* and *Neptune*. Much has been said of the splendor of the Saturnian sky as seen from the planet itself, with the great ring arching over the heavens and the satellites circling along it. It is far more likely that, if this splendor is seen at all, it is from the satellites, from which, especially from *Japetus*, the most remote, whose orbit lies outside of the plane of the ring, a most magnificent view of the noble planet, with its rings and the other satellites, could be had. *Saturn* from *Japetus* would look as it does to us with a magnifying power of about 350 diameters; or, to use another illustration, the ball of the planet would look about three and a half times the diameter of the moon, and the rings nearly nine times that diameter.

We come next, in our inward course, to the planet *Mars*. Here, for the first time, we begin to see positive signs, instead of mere negative possibilities, of what we have been looking for.

We have noticed, as we passed this planet on our way outward from the sun, the similarity of its surface to that of the earth, the permanent configurations on it of what we have a good right to assume to be land and water. We have seen its polar ice-caps, its green seas, and red earth; and we know that it has an atmosphere which, though not as dense as our own, is still enough, as it would seem, for life. We know that it has a day almost exactly the same as ours, and not only this, but seasons substantially like our own, as far as the vary-

ing angle is concerned at which the sun's rays strike its surface, though it is true that these are a good deal interfered with by the considerable variation in the sun's heat, depending on the eccentricity of its orbit; still this would not amount to so very much. In this latitude, for instance, on the earth, we receive more than three times the heat from the sun in one day in the middle of June than we get in the middle of December, on any given area, say a square mile or a square yard, owing to the combined influence of the greater height of the sun above the horizon and the greater length of the daylight. About the same would be the case in the same latitude on *Mars*. The effect of the eccentricity would be quite considerable, making the sun's heat once and a half as great at the nearest point as at the farthest; still, if we can sustain the three-fold multiplication, a half as much again might be added, without the variation becoming intolerable. Moreover, this great variation would only occur, when the summer solstice of one of the hemispheres coincided with the point of nearest approach to the sun. During half the time, the eccentricity would tend to moderate, instead of to accentuate, the seasons, as it does with us here in the northern hemisphere now.

Mars is certainly the most favorable case for those who would believe the planets to be habitable. It really seems that it might be inhabited by men like ourselves. As remarked on a previous occasion, its climate seems, from the small size of the polar ice-caps, to be warmer than that of the earth, in spite of its greater distance from the sun.

As to *Venus* and *Mercury*, we can hardly form any decided opinion. They seem to be surrounded by dense, cloudy atmospheres, which may tend, in a great measure, to keep off the intense heat of the sun. A rather singular thing has lately been observed, or, at least, thought to be observed, by SCHIAPARELLI, with regard to *Mercury;* that is, that some markings on it seem to indicate that its period of rotation round its axis is the same as that of its revolution round the sun; or, in other words, that it acts as our moon does, keeping always the same face toward the center round which it revolves. This would seem to be borne out by the white spot on the black disc of the planet, which has been reported by various observers as regularly visible at the time of its transits across the sun's face. If this white spot is a real object, it would seem that it is always turned away from the sun. If this can be accepted, it would be, of course, to some extent, an argument against the habitability of *Mercury;* as its inhabitants would be deprived of the vicissitude of day and

night, and the side turned constantly toward the sun would probably, in spite of everything, become uncomfortably warm.

Now that we have—though quite hurriedly—completed our consideration of the planets as to their suitableness for habitation, what answer shall we give to the question with which we started? Before giving it, another reflection must be made, which will brighten the prospect a good deal for those who would fain believe all these magnificent orbs to be the abode of life like ours.

It is this: Will it not suffice to satisfy the minds of those who cannot believe that these great globes, similar in so many respects to ours, can be tenantless, to hold that they are habited for a portion, though not for the whole, of their history? For myself, I do not feel the craving for the plurality of worlds, as it is called, which seems to be general. I must confess that I have never been able, personally, to feel the force of the argument which strikes most minds so powerfully, that these habitations could not have been made by their Creator except to be actually inhabited. The mere size and mass of an object seems to me to amount to little. *Jupiter* itself, or *Saturn*, with its beautiful ring and satellite system, simply as a mass of matter or a mechanical construction, is a far less noble creation of God than a single human soul; nor does it seem to me that the mere size of these planets makes them much more remarkable, or requires more reason for their formation, than if they were only a few feet in diameter. The technical study of astronomy, no doubt, has the effect of reducing the impression made by mere magnitude on the mind; whether this is a delusion or the removal of a delusion, of course, I cannot say. That the mere size of a body itself does not require inhabitants for it, seems plain from the generally-confessed impossibility of inhabiting the sun, the surface of which far exceeds that of all the planets put together; that is to say, that it does not require them at every moment; but it may be, if you will, that it does require that at some time or other it should be used for such a purpose. The general belief is, we may say, an argument for the fact.

And, of course, the argument for the plurality of worlds is strengthened, if, beside size or standing-room, as we may say, we see some other conditions indicating conveniences for life, though they be imperfect or incomplete. If we see a house with only its framework up, we say, "Nobody lives there now, but it is being built for some one"; and if we see a house in ruins, we say, "Somebody lived there once."

Now, this is certainly very plausible ; and I think that the history of our own earth, so far as it can be learned from science, increases the probability of the opinion that the planets, and perhaps even the sun itself, were made to be inhabited at some time or other. The teaching of geology is that our own earth was for a long time uninhabitable, that it subsequently became fitted to be the abode of the inferior and simpler forms of life, and finally became ready for the reception of man ; and we can hardly shut our eyes, either, to the scientific conclusion, that from the operation of natural causes alone, it would at some time in the distant future become uninhabitable again, though in a different way ; that it would become, simply from the changes which must come from the gradual progress of cooling necessarily going on in the solar system, no longer a building which its Creator is forming, but a cold and desolate ruin like the moon.

The history of this earth is probably the history of the other planets, if they are to be allowed to develop in a natural way. Some, like the moon, seem to have passed further along the road than our own planet. This is probably the case with *Mars*, the most habitable in appearance of them all. As a rule, of course, the smaller a planet is, other things being equal, the more rapidly it will cool from its originally incandescent state ; *Mars* then should be older,—that is, have passed through more of its successive changes, than we. It looks so, besides. The seas seem to be drying up, the air thinning away. On the other hand, the great superior planets, *Jupiter*, *Saturn*, *Uranus* and *Neptune* are young, and have the best part of their life before them.

What portion of the total life of a planet is that in which it becomes habitable by beings like ourselves, we cannot very well determine. If we accept the estimates of geology, the time that the human race has been here is a very small part of our world's history. But how much longer this earth would naturally remain a possible residence for us we cannot say with accuracy. It would seem probable, however, that the period in which all the necessary conditions of life would simultaneously exist, can hardly be a very considerable part of the whole. The inhabitants of a planet in the stage of decadence from its most perfect state could, no doubt, on the principle of the "survival of the fittest," accommodate themselves to their more unfavorable circumstances for a good while ; but the time would come when the struggle would have to be abandoned.

If it is true that the period of habitability by the high organisms

is a small part of a planet's life, obviously the chance is small for any planet in particular of its being in that period now or at any particular time. We must say that it probably is not, unless we have, as in the case of *Mars*, some positive indications that it is. So far as we can trust such positive indications, *Venus* and *Mercury* are approaching that part of their life that the earth is in at present; the earth seems at one time to have had the very dense and vaporous atmosphere that apparently surrounds them now.

To sum up now briefly, the results to which our examination has led us: In the first place, our observations should probably be modified by the very plausible theory, now generally adopted, that all the bodies of our system, sun and planets, have passed and are passing through a series of changes, beginning with a state of great heat and expansion, in which and for a long time no life is possible on their surfaces, and in a great part of which indeed, as in the case of the sun at present, they can hardly be said to have a surface at all. As the changes due to the gradual cooling and contraction proceed, life in its simpler forms becomes possible, and in course of time a state is reached like that of this globe at present, in which the conditions for highly organized life are at their best.

Assuming this, the question of fact becomes, is there any other planet or satellite in the system in which this state of maximum habitability, if we may so call it, now exists? We can say with great confidence that it does not on *Jupiter* and *Saturn;* that the chances are much against it on *Uranus* and *Neptune;* that *Venus* and *Mercury* are probably still too young for it; but that there is a reasonable probability for it on *Mars*, though this planet seems to be passing into the decline, the steps of which we do not clearly understand, but of which we see perhaps the final result in the torn, scarred, and desolate surface of our own satellite. With regard to the satellites of the great planets, we have absolutely to suspend judgment. As the period of habitability is probably less than that of development, though of this we are far from certain, the chances are perhaps against any particular one of them being in that state just now; but as they number at least seventeen altogether, the probability that some one of them may be habitable is not so inconsiderable. As to the satellites of *Mars*, and the swarm of asteroids, they seem to be too small to retain an atmosphere sufficient for the support of beings like ourselves. If they had a course to run, it has probably been concluded long ago.

In speaking of the natural life and development of the planets,

we are, of course, looking at the matter merely from a scientific point of view. Of course, most Christians believe that long before the natural life of this earth would be concluded, it will suffer a final catastrophe which will at least close the history of the human race on it as it exists now. Such catastrophes may, of course, occur to any planet by natural as well as supernatural causes; by collision with some other body, for instance; or to the whole planetary system, by some large body striking on the sun. One thing which we may perhaps look forward to is a time when, after the death or destruction of all the planets, the sun itself ceasing to be a luminary and furnace for bodies circulating round it, may itself become the great seat and home of life. In theorizing on this point we have no past experience or history to guide us. We shall see as we go on to discuss the stellar systems that we have at least one case, perhaps more than one, of a body sun-like in dimensions, which has either ceased to give light, or never gave it. It is only in exceptional cases that we have any means of recognizing the existence of such bodies; they may be very numerous. Neither can we tell whether the other innumerable brilliant suns scattered through space have attendant planets like our own. But it would be strange if they had not. If any considerable proportion of them have, evidently the chance that there are other habitable worlds in the universe becomes very great.

ON HYPERBO-ELLIPTIC FUNCTIONS.

By Irving Stringham, Ph. D.

I.

The geometrical definition of the Legendrian, or cyclo-elliptic functions by means of a circle, as given by the late M. Halphen in his *Traité des Fonctions Elliptiques*, t. I, p. 2, suggests an analogous construction for the equilateral hyperbola, through which what I venture to call the *hyperbo-elliptic functions* may in like manner be defined. M. Halphen's treatment is strictly geometrical, but the analytical form of presentation is better adapted to the analogous theory here sketched in outline.